UNIVERSITY OF TASMANIA

Geology of the Kapit Ore Zone and Comparative Geochemistry with Minifie and Lienetz Ore Zones, Ladolam Gold Deposit, Lihir Island, Papua New Guinea

by

Mathieu Ageneau

M.Sc.

ARC Centre of Excellence in Ore Deposits

School of Earth Sciences

CODES

Submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

University of Tasmania

July 2012

Statement

This thesis contains no material which has been accepted for the award of any other degree or diploma in any tertiary institution and, to the best of my knowledge and belief, contains no copy or paraphrase material previously published or written by another person, except where due reference is made in the text of the thesis.

Date: 10/03/2013

Signature:

Authority of access

This thesis is not to be made available for loan or copying until January 1st, 2017. Following that date the thesis may be available for loan and limited copying in accordance with the *Copyright Act 1968*.

Date: 10/03/2013

Signature:

For my grandparents

Roger Ageneau

(1924 – 2009)

and

Georgette Ageneau

(1924 – 2010)

True knowledge exists in knowing
that you know nothing.

Socrates

Abstract

The 56 Moz Ladolam gold deposit, with an average gold grade of 2.42 g/t, has previously been recognised as the world's largest known epithermal gold deposit. It is located on Lihir Island, in the New Ireland Province of Papua New Guinea, and is part of the Tabar-Lihir-Tanga-Feni chain of Pleistocene alkalic volcanoes. Alkalic magmatism occurred in an extensional tectonic regime, in a location where initial arc magmatism was related to subduction with the Manus-Kilimailau trench, but was later reactivated as a back arc due to the subduction of the Solomon Sea plate along the New Britain trench. Lihir island is made up of at least five volcanic blocks, and is surrounded by an uplifted Quaternary limestone reef. The Ladolam gold deposit is located on the eastern side of the island, in the Luise volcanic edifice. Mineralisation is localised along north-dipping structural zones. There are two large ore zones (Minifie and Lienetz) and several smaller (Kapit, Coastal, Pacific and Borefields) in a 3 km^2 surface area.

The Kapit ore body is hosted by diverse volcano-sedimentary and hydrothermal facies. The coherent facies include basalt, diorite and andesite. The volcaniclastic facies comprises two types of polymict matrix-supported breccia. Hydrothermal breccia facies include anhydrite-carbonate-quartz-cemented breccia and pyrite-cemented breccia.

The Kapit ore zone is characterised by five different paragenetic stages. Porphyry-style stage 1 features were not observed at Kapit, but are preserved at Lienetz and Minifie. Stage 2 anhydrite-cemented breccias and veins at Kapit are associated with porphyry-style biotite-K-feldspar-magnetite potassic alteration. Stage 3A pyrite-cemented breccia, stage 3B quartz-chalcedony-pyrite-cemented breccias and veins, and stage 3C carbonate-anhydrite-quartz-cemented breccias and veins are all associated with phyllic alteration. In contrast, stage 4 disseminated pyrite and pyrite veinlets are associated with intermediate argillic to advanced argillic alteration assemblages.

Gold at Kapit, and elsewhere at Ladolam, is contained in refractory pyrite and marcasite. The different types of pyrite and marcasite identified from the Kapit, Lienetz and Minifie ore zones are acicular, banded, colloform, euhedral, framboidal and anhedral. LA-ICPMS analyses have revealed that the colloform, framboidal, anhedral ± acicular marcasite-pyrite grains have the highest contents of gold and other trace elements.

Paragenetically, highest gold contents in Fe-sulfides occur in stage 3A (Lienetz), 3B (Kapit) and 3C (Minifie) quartz-chalcedony-pyrite-cemented breccias and veins, stage 3A (Kapit) and stage 3B (Minifie) pyrite-cemented breccias, stage 2B (Lienetz) quartz-anhydrite-barite-cemented breccias, and stage 4 (Kapit) disseminated pyrite and pyrite veinlets. At the deposit scale, Au in pyrite is positively correlated with Ag, As, Sb, Cu, Se, Pb, and Tl.

Analyses of fluid inclusions, coupled with observed mineralisation and alteration mineral assemblages from stage 2 (Kapit and Lienetz), show that mineralising fluids were relatively hot (>250°C), saline (4-6 wt% NaCl eq. in average) and had near-neutral pH. In contrast, the mineralising fluids from stage 3 (Kapit, Lienetz and Minifie) were significantly cooler (150-250°C), more dilute (1-4 wt% NaCl eq. in average), and acidic. Trends in fluid inclusion data are interpreted to be the result of mixing between magmatic-hydrothermal fluids (5-10 wt% NaCl eq., >350°C) and steam–heated seawater (~3.2 wt% NaCl eq., 150-200°C). Distinct increases of salinity suggests that adiabatic boiling occured during mineralisation; most likely during multiple phases of hydrothermal brecciation. Gold is likely to have been transported as a hydrosulfide complex (e.g. $Au(HS)_2^-$) and boiling and/or mixing destabilised the Au-hydrosulfide complex and triggered gold precipitation. Gold contents in the mineralisisng fluids were up to 8 ppm, based on LA-ICPMS analyses, much higher than detected in the modern geothermal waters (up to 16 ppb). The positive correlation of Ag, Tl, As and Sb with Au in fluid inclusions imply that Ag, Tl, As and Sb were transported as hydrosulfide complexes such as $H_2As_3S_6^-$, $HSb_2S_4^-$, $AgHS_{(aq)}$ and $TlHS_{(aq)}$.

Ladolam is concluded to be a hybrid gold deposit that contains early porphyry-style alteration features, semi-massive pyritic ores hosted by hydrothermal breccias that have affinities with shallow submarine VHMS-style gold mineralisation, late-stage low sulfidation style epithermal veins and breccias and modern subaerial to submarine geothermal features. The history of the Ladolam deposit, including the Kapit, Lienetz and Minifie ore bodies is composed of a succession of catastrophic events triggering formation of different mineralised breccias and veins in an environment that evolved from submarine to subaerial after a major sector collapse event. Mineralising events can be separated into two distinct phases, transitional porphyry-VHMS (pre-sector collapse) and VHMS-epithermal (post-sector collapse).

Acknowledgements

I have benefited greatly from the support, knowledge, advice, assistance and friendship of many people over the course of this research. It is not possible for me to thank everyone, so I want to extend a general acknowledgement to each of them.

First I would like to thank my principal supervisor Dave Cooke for his endless support, guidance, encouragement and patience. Thank you Dave for teaching me the finer art of writing, and for the sacrifice of many of your red pens in the final stages of this research. Finishing this thesis would not have been possible without you.

To my two additional co-supervisor Bruce Gemmell and Leonid Danyushevsky, thank you for your advice, guidance and ideas throughout this research.

I would also like to thank Gary Davidson, Zhaoshan Chang, Huayong Chen, Sarah Gilbert, Jamie Wilkinson, Ross Large and Sebastien Meffre for providing stimulating and insightful discussions, their input improve the content of this study.

The CODES and Central Science Laboratory (CSL) support staff are greatly thanked for their support. First, I would like to thank Keith Dobson and Christian McKenzie for their computer technical support, to Simon Stephens and Al Cuizon for their lapidary work, to Peter Cornish and Izzy Von Lichtan for their "MacGyvering" technical support, to June Pongratz for her assistance with printing, to Karen Mollross, Helen Scott, Christine Higgins, Caroline Mordaunt, Claire Rutherford, Rose Pongratz, Deborah Macklin and Nilar Hlaing for taking care of all administrative and financial matters, to Huayong Chen for his help with PIMA analyses, to Karsten Goemann and Sandrin Feig for their help collecting BSE, CL and microprobe data, to Thomas Rodemann for his help with Raman spectrometry, to Sarah Gilbert, Ian Little, Leonid Danyushevsky and Marcel Guillong for their help and guidance with my laser ablation study, and to Jamie Wilkinson for his help with the fluid inclusion study.

Financial and logistical support was provided by Newcrest, and thanks go to Jon Rutter, Dean Collett, Kathryn Stewart, and Kylie Braund. A special thank to Tim O'Sullivan, Al Mom, Fiona Karaut, Stephanie Grabovickic, Benjamin Likia, and other geos and core shed samplers for their endless support and friendship on site at Lihir.

I'm greatly thankful to several institutions for their financial support: CODES – University of Tasmania for the postgraduate scholarship, the SEG Hugh E. McKinstry fund for supporting additional research, the UTAS Graduate Research Office, the SEG and the SGA for supporting travel expenses related to conferences.

To all my CODES colleagues and friends, I can't thank you enough for your support, camaraderie, friendship during this adventure. To my friends back in France, Switzerland and UK, thank you for your support and encouragement over the years.

I would like to thank my parents and family for their love, support and constant encouragement during my academic career which has taken me to places far away from France.

Finally and most importantly, to my wife Lindsey, I can't thank you enough for your amazing patience, love, help and support over the last 3.5 years. Thank you so much for changing my life and for always being there for me when needed. I promise to repay you with NZ holidays. Finally, I can't wait to share the pleasure and happiness of parenting with you.

Table of contents

Chapter 3 Geology of the Kapit ore zone

Chapter 4 Alteration and mineralisation of the Kapit ore zone

Chapter 5 Sulfide mineral chemistry

Chapter 6 Fluid inclusions